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UTILIZATION OF FERMENTED UNCONVENTIONAL PLANT FEEDS BY GENETICALLY IMPROVED FARMED TILAPIA (GIFT): PERFORMANCE, SURVIVAL, AND COST IMPLICATIONS

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ABSTRACT

This study evaluated the ability of Genetically Improved Farmed Tilapia (GIFT) to utilize unconventional low-cost feeds formulated from plants and animal by-products. Over 58 days, GIFT fingerlings were fed one of four feeds: a commercial feed (T0), an unfermented unconventional feed (T1), a fermented unconventional feed (T2), and a 50:50 commercial–fermented (T3). Fish fed with commercial feed (T0) showed the highest growth (24.1 g; Specific Growth Rate (SGR) = 6.65% day^{-1}), while fermented (T2) and unfermented (T1) feeds supported moderate growth (5.7–7.2 g; SGR ≈ 3%). The hybrid feed (T3) yielded intermediate performance (17.6 g; SGR = 5.10% day^{-1}) with 100% survival, indicating good adaptation of GIFT to the partially substituted feed. The commercial group had the lowest survival (76.7%). On a per-kilogram basis, the commercial feed was ₦1380 more expensive than the unconventional feed (₦1500 vs. ₦120), representing a cost difference of over 90%. This substantial gap contributed to approximately 50% lower feed-related production costs in the hybrid feeding system. Feed-efficiency indices indicated that biomass gain per feed offered and protein efficiency were highest in the commercial and hybrid diets, while feed cost per unit biomass gain was lowest in the fermented unconventional diet, highlighting clear trade-offs between growth and cost. Although growth was slower, high survival due to water-quality stability confirmed the potential of GIFT to utilize fermented low-value feed. This suggests a viable pathway for sustainable and cost-efficient aquaculture using improved tilapia strains. Enhancing the palatability of fermented feeds is recommended to improve growth outcomes in future applications.

Keywords: Tilapia, plants, Fermentation, Survival, Feed Cost

INTRODUCTION

Feed cost remains one of the major constraints in aquaculture, representing about 50 - 60% of total production expenses (Naylor *et al.*, 2021). This has intensified the search for inexpensive, locally available, and sustainable feed ingredients that do not compete with human or livestock food sources. Aquatic macrophytes such as *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce) often regarded as environmental nuisances in tropical water bodies offer potential as alternative protein sources (Pandey, 2020; Kumar *et al*., 2022). Their use could simultaneously reduce feed cost and contribute to ecological management of invasive plants. Although catfish dominate aquaculture in Nigeria, high feed costs continue to limit profitability. Tilapia farming remains underdeveloped, largely due to the slow growth of local strains and limited awareness of improved lines such as

the Genetically Improved Farmed Tilapia (GIFT), which demonstrates superior growth and feed efficiency (WorldFish, 2021; Tran et al., 2021).

A major limitation of incorporating raw aquatic plants in fish feed is their high fibre content, low digestible protein, and Anti-Nutritional Factors (ANFs), which reduce nutrient utilization (Kokou and Fountoulaki, 2018). Fermentation has emerged as an effective method to improve the nutritional quality of unconventional feed ingredients by increasing crude protein, reducing fibre, and deactivating ANFs, while also enhancing digestibility and gut health (Saha and Ray, 2011; Sun et al., 2023; Lian *et al.*, 2024). Fermented aquatic plants have shown higher inclusion tolerance in tilapia feed compared with conventional feed sources (El-Sayed, 2003; Emshaw *et al*., 2023).

Incorporating animal by-products such as blood meal that is rich in crude protein and lysine, can improve protein balance while significantly lowering feed costs (Kirimi *et al*., 2016; Macusi *et al*., 2023). When combined with fermented plants, these by-products offer a sustainable solution for converting low-value biomass into productive aquaculture inputs. Fermentation enhances digestibility, which may also contribute to better water quality. Despite growing interest in sustainable aquafeeds, there remains a gap in developing affordable, locally sourced feed tailored for small-scale tilapia farming. Most prior studies have used plants at low inclusion levels or focused primarily on growth, often neglecting critical trade-offs such as survival, water quality, and economic viability. The potential of fermentation and partial commercial feed replacement has been underexplored especially in recent times. This study addresses these gaps by evaluating high-inclusion (up to 49%) fermented and unfermented plants combined with animal by-products, assessing their effects on fish performance, survival, water quality, and feed cost. Therefore, this study aimed to evaluate the ability of GIFT tilapia to utilize fermented unconventional feed made from locally available aquatic plants and animal by-products. We hypothesized that the genetic enhancement of GIFT tilapia would support the efficient use of low-value feed without compromising survival and that fermentation would enhance the nutritional quality and digestibility of plant ingredients.

MATERIALS AND METHODS

Experimental Site and Fish Husbandry

The feeding trial was conducted at the Aquaculture Unit of the Department of Animal and Environmental Biology, Delta State University, Abraka, Nigeria. A total of 240 genetically improved Nile tilapia (*Oreochromis niloticus*, GIFT strain) fingerlings were sourced from a local hatchery (Ughelli, Delta State). Fish averaged approximately 0.66 ± 0.06 g initial body weight and 3.51 ± 0.04 cm initial body length. They were acclimated to laboratory conditions for one week prior to the experiment, during which they were fed a commercial feed. The fish were then randomly distributed into 12 plastic tanks (32 L capacity each, filled with 30 L of water). Each tank was part of a flow-through system with aeration. Ethical approval was granted by the Faculty of Science Research and Ethics Committee (REC/FOS/2026/02), and all experiments were performed in accordance with the NIH Guideline for the Care and Use of Laboratory Animals.

Feed Ingredient Collection and Preparation

Plant materials: Three readily available and abundant plants were selected as basal ingredients for the unconventional feed: elephant grass (*Pennisetum purpureum*), water hyacinth (*Eichhornia crassipes*), and

water lettuce (*Pistia stratiotes*). Fresh water hyacinth and water lettuce were harvested from local water bodies and ponds around the university campus (Abraka, Nigeria). Elephant grass was collected from university fields. All plant materials were rinsed thoroughly with clean water to remove debris and aquatic organisms. The cleaned biomass was chopped into small pieces to facilitate drying and fermentation. The pieces were then dried in a hot-air oven at 70 °C, ground into coarse powder, and stored in airtight containers.

Fermentation of plant substrates: For the fermented treatment feed (T2), some portions of the plant powders were subjected to solid-state fermentation (SSF) using a homemade lactic acid culture. The fermentation inoculum was prepared by first fermenting rice wash water (the starchy water obtained from rinsing rice grains). Rice wash water was placed in airtight containers and left to ferment anaerobically for 2 weeks to encourage natural lactic acid bacteria proliferation. After 2 weeks, fresh milk (as a source of *Lactobacilli* and nutrients) was added to the fermenting liquid and left for another 2 weeks. Then, a small amount of baker's yeast (*Saccharomyces* sp.) and molasses (sugar source) were mixed in, and fermentation continued for one additional week. This liquid culture serves as the inoculum for fermenting the plant substrates.

The plant substrates (elephant grass, water hyacinth, water lettuce) were each packed tightly into separate clean plastic barrels for SSF. The prepared lactic fermentation liquid was added to each barrel just enough to moisten the plant material. The barrels were sealed airtight to create anaerobic conditions. Fermentation proceeded for 14 days at ambient temperature. Barrels were briefly opened every 2–3 days to release accumulated gases (CO_2) and then resealed. After 14 days, the fermented plant materials were removed and dried in the oven at 70 °C. The dried fermented materials were ground into fine powders and stored in airtight containers.

Other ingredients: In the unconventional feed, blood meal (BM) was used as the primary animal protein source. Fresh blood was collected from a local abattoir (mostly cattle blood), boiled to coagulate proteins, then dried and ground to produce blood meal powder. Two rendered animal fats were included: tallow (beef fat) and lard (pork fat), obtained by slow heating of cow and pig fatty tissue, respectively, to remove water and impurities. These fats were solid at room temperature and were added in melted form during feed mixing. Wheat offal from a local mill served as a carbohydrate source. A commercial vitamin mineral premix and salt (NaCl) were added in small amounts to ensure micronutrient adequacy. All ingredients were sourced locally in Delta State, Nigeria.

Feed Formulation

Four (4) feeds were designed for this experiment:

i. T0 (Conventional Commercial Feed, CCF): An extruded commercial catfish feed (40% crude protein) purchased from a feed supplier, used as the control feed.
ii. T1 (Unfermented Unconventional Feed, UUF): A completely plant- and by-product-based feed using unfermented plant meals. The formulation (dry-matter basis) was: 12% water hyacinth meal, 15% water lettuce meal, 22% elephant grass meal (all unfermented); 36% blood meal; 8% wheat offal; 3.5% tallow; 2% lard; 1% vitamin premix; 0.5% salt. This formulation was designed to target 40% crude protein and 12% crude lipid, guided by a fish feed formulation software (Table 2). The high inclusion of blood meal was to boost protein

content given the moderate protein levels of the plant ingredients. Ingredients were weighed, thoroughly mixed with water to form a mash, and then pelleted through a pelleting machine. Pellets were oven-dried at 60 °C and stored in airtight containers.

iii. T2 (Fermented Unconventional Feed, UFF): Same formulation as T1, except that fermented water hyacinth, water lettuce, and elephant grass meals were used in place of the unfermented meals. The pelleting procedure was the same. Some pellets of each feed were set aside for proximate analysis.

iv. T3 (50% Hybrid feed): A 1:1 blend (by mass) of the commercial feed (T0) and the fermented feed (T2). To prepare it, equal quantities of CCF and UFF pellets were ground and hand-mixed thoroughly, then re-pelleted to ensure homogeneity. The hybrid feed provided roughly 50% of nutrients from the commercial formula and 50% from the unconventional formula. This treatment tested whether partial replacement can maintain high growth while cutting feed cost.

Blood meal was included at a relatively high level (~36% of the diet) to serve as the principal protein source and to achieve a target crude protein level comparable to the commercial feed while fully excluding fishmeal and soybean meal. This formulation was intentionally designed to test the feasibility of a fishmeal-free, low-cost diet based on locally available animal by-products, rather than to optimize growth performance.

All feeds were pelleted and then crushed to a size suitable for the fingerlings. Feeds were stored in sealed containers and fed to the fish for 58 days

Feed analysis

Proximate composition of the experimental feed was determined using standard methods (AOAC, 2019). Samples of each feed (including the control feed and the unconventional feeds) were analysed for: moisture content, crude protein (Kjeldahl nitrogen × 6.25), crude fat (ether extraction), crude fiber (digestion method), total ash (550 °C muffle furnace), and nitrogen-free extract (NFE) by difference. Table 1 shows the proximate composition results for the control and unconventional feed ingredients, and Table 3 shows the proximate composition of the formulated feed.

Experimental Design and Data Collection

Four dietary treatments were randomly assigned to triplicate tanks (n = 3 tanks per treatment; 20 fish per tank). Fish were fed four times daily (08:00, 12:00, 16:00, and 19:00) following standard tilapia feeding practice. Feeding was initially set at approximately 10% of total body weight per day and adjusted progressively as fish grew and appetite increased. During the first 29 days of the experiment, all tanks received an estimated 1.4 g feed $tank^{-1}$ day^{-1}. Thereafter, feeding rates were adjusted based on observed biomass and feed acceptance, resulting in average daily feed inputs of approximately 5.0 g $tank^{-1}$ day^{-1} for the commercial feed group, 2.6–3.8 g $tank^{-1}$ day^{-1} for the unfermented and fermented unconventional feed groups, and 2.5–5.0 g $tank^{-1}$ day^{-1} for the hybrid diet group until the end of the 58-day trial.

Tanks were cleaned and approximately 70–80% of the water was exchanged every three days using a flow-through system combined with periodic renewal to maintain water quality. Fish were exposed to ambient natural photoperiod (~12 h daylight), and behaviour and health status were monitored daily. The experiment followed a completely randomized design.

Fish were weighed (initial mean weight = 0.66 ± 0.06 g) and measured for standard length (initial mean = 3.51 ± 0.04 cm) at the beginning and end of the 58-day trial. Total tank biomass was recorded bi-weekly to adjust feeding rates, while individual measurements during the trial were avoided to minimize handling stress. At the end, all surviving fish were counted to determine survival, then individually weighed and measured for standard length to calculate condition factor. Each tank was considered the experimental unit. Individual fish within each tank were treated as subsamples, and tank means were used for all statistical analyses.

Growth performance metrics were calculated as follows:

i. Weight Gain (WG, g) = Final mean weight – Initial mean weight.
ii. Length Gain (LG, cm) = Final mean length – Initial mean length.
iii. Specific Growth Rate (SGR, % day $^{-1}$) = 100 * [ln(final mean weight) – ln(initial mean weight)] / duration in days.
iv. Feed Conversion Ratio (FCR) could not be accurately measured due to group feeding (crushed feeds and continuous water flow prevented quantifying uneaten feed).
v. Condition Factor (K) = (W / L^3) * 100, where W = individual body weight (g), L = individual total length (cm).
vi. Survival Rate (%) = (Number of fish harvested / Number stocked) * 100.

Efficiency Metrics Calculation:

Because fish were group-fed in shared tanks, individual feed intake could not be determined; therefore, conventional feed conversion ratio (FCR) was not calculated. Alternative efficiency indices (PER, BGF, and FCCR) were used to evaluate dietary performance.

i. Biomass Gain per Feed Offered (BGF) = Total biomass gain (g) / Total feed offered (g)
ii. Protein Efficiency Ratio (PER) = Total biomass gain (g) / Total protein offered (g)
iii. Feed Cost Conversion Ratio (FCCR) = Total feed cost (₦) / Total biomass gain (g)

Water quality monitoring

A multi-parameter water quality meter was used to measure pH, electrical conductivity (EC), total dissolved solids (TDS), and oxidation–reduction potential (ORP). Dissolved oxygen (DO) was measured using a DO meter. Measurements were taken in each tank at two points in the water-change cycle: immediately after a water change ("D0", representing fresh water conditions) and just before the next water change, three days later ("D1", representing water that had accumulated fish metabolic wastes and feed residues). By comparing D0 vs D1 values and across feeds, we inferred how each feed impacted water quality deterioration. Temperature was ambient (27–29 °C) and did not vary markedly between tanks. Additionally, any visible differences in water clarity were noted qualitatively.

Cost Analysis

An economic analysis was performed to compare feed costs. Local market prices of each ingredient were recorded (in Naira, ₦). Using the inclusion rates in the formula, the cost to produce 1 kg of the unconventional feed was calculated by summing the cost contributions of each ingredient. This was compared to the market price of the commercial feed per kg. Table 4 details the ingredient costs and the total formulated feed cost per kg. (Labour cost are not included, so the analysis considered just the raw ingredient and processing cost as a baseline for potential savings).

Statistical Analysis

All data were analyzed using the tank as the experimental unit. For each response variable, individual fish measurements within a tank were first averaged to obtain a single tank mean. These tank means (n = 3 per treatment) were then used for statistical comparisons. One-way analysis of variance (ANOVA) was applied to test for treatment effects, followed by Tukey's HSD post-hoc test when significant differences were detected ($P < 0.05$). Statistical analyses were performed using SPSS version 25.

RESULTS

Growth Performance

Weight gain (g) of fish varied markedly with feed (Figure 1). Fish fed the commercial control feed (T0) had a final mean weight gain of 24.13 ± 1.83 g. In contrast, fish fed the unfermented unconventional feed (T1) gained only 5.73 ± 0.49 g, and those fed the fermented unconventional feed (T2) gained 7.19 ± 0.43 g. Fermenting the plant ingredients thus improved weight gain by about 26% (T2 vs T1), but the gains in both T1 and T2 remained much lower than the control. The hybrid feed (T3, 50% CCF + 50% UFF) yielded intermediate growth: T3 fish had a mean weight gain of 17.64 ± 1.77 g, which is about 73% of the weight gain achieved with the full commercial feed. These differences in weight gain were statistically significant (ANOVA, *P<0.05*). Figure 1 illustrates the mean weight gain per fish across treatments.

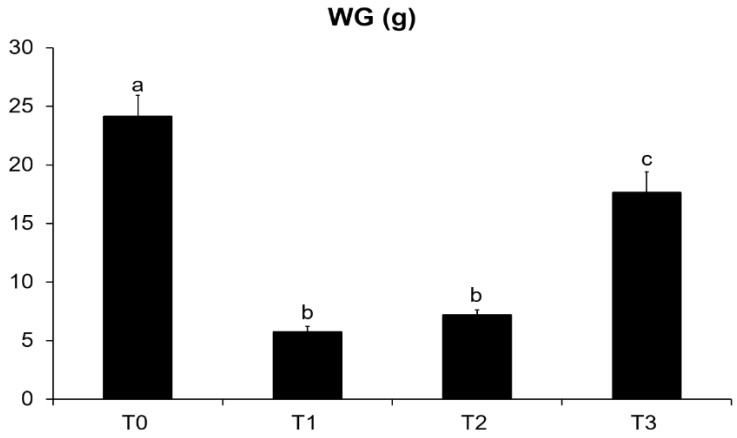


Figure 1. Mean Weight Gain (WG) (g per fish) of *Oreochromis niloticus* under different feed treatments (mean ± SD, n = 3). CCF = conventional commercial feed (T0), UUF = unfermented unconventional feed (T1), UFF = fermented unconventional feed (T2), and Hybrid = 50% CCF + 50% UFF (T3).

A similar pattern was observed in **linear growth** (length increment). Fish fed the commercial feed had a mean total length gain of 7.83 ± 0.28 cm. Fish on the unfermented feed (T1) grew by 4.43 ± 0.25 cm, and those on the fermented feed (T2) grew by 4.75 ± 0.31 cm. The hybrid feed group (T3) showed a length gain of 7.27 ± 0.55 cm, nearly as high as the control. These differences were also significant ($p<0.05$). Figure 2 shows the mean length gains across the different treatment.

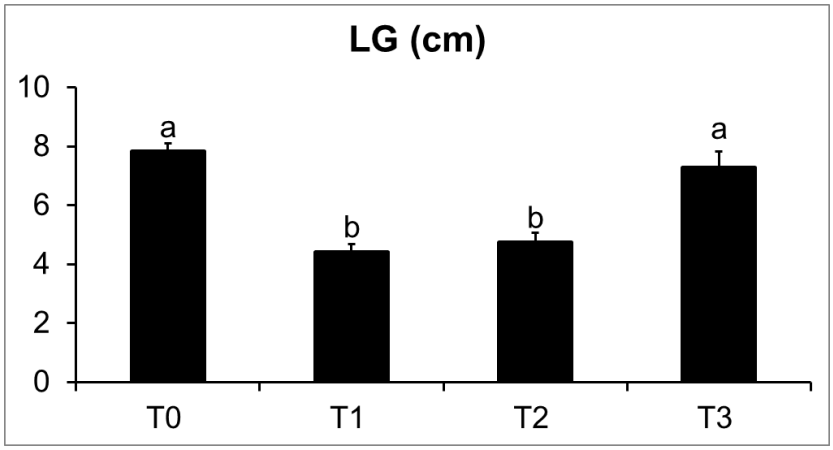


Figure 2. Mean total Length Gain (LG) (cm per fish) of tilapia in each treatment (mean ± SD). CCF = conventional commercial feed (T0), UUF = unfermented unconventional feed (T1), UFF = fermented unconventional feed (T2), and Hybrid = 50% CCF + 50% UFF (T3).

Specific Growth Rate (SGR) results showed in Figure 3, mirrored the weight gain outcomes. The highest SGR was recorded in fish on the commercial feed (6.65 ± 0.12%/day). Fish on the unfermented feed grew at only 3.00 ± 0.11%/day, and those on the fermented feed had a similar SGR of 3.08 ± 0.17%/day. The hybrid feed produced a significantly higher SGR (5.10 ± 0.16%/day) than T1 and T2, though still below the control ($P<0.05$).

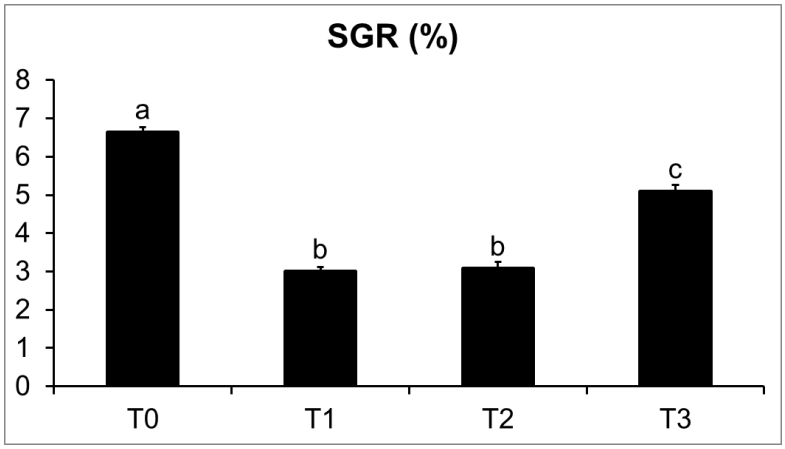


Figure 3. Specific growth rate (% body weight per day) of tilapia in each treatment (mean ± SD). CCF = conventional commercial feed (T0), UUF = unfermented unconventional feed (T1), UFF = fermented unconventional feed (T2), and Hybrid = 50% CCF + 50% UFF (T3).

Condition Factor (K) provides an index of the fish's body robustness (weight relative to length) (Figure 4). The fish fed the commercial feed had the highest K (1.82 ± 0.12). Fish on the unfermented feed had the lowest K (1.56 ± 0.02), and those on the fermented feed had K = 1.62 ± 0.07. Fish on the hybrid feed had an intermediate K of 1.71 ± 0.11 (Figure 4). Thus, while the plant-based feeds resulted in slightly leaner fish, all K values were within a generally healthy range (around 1.6–1.8).

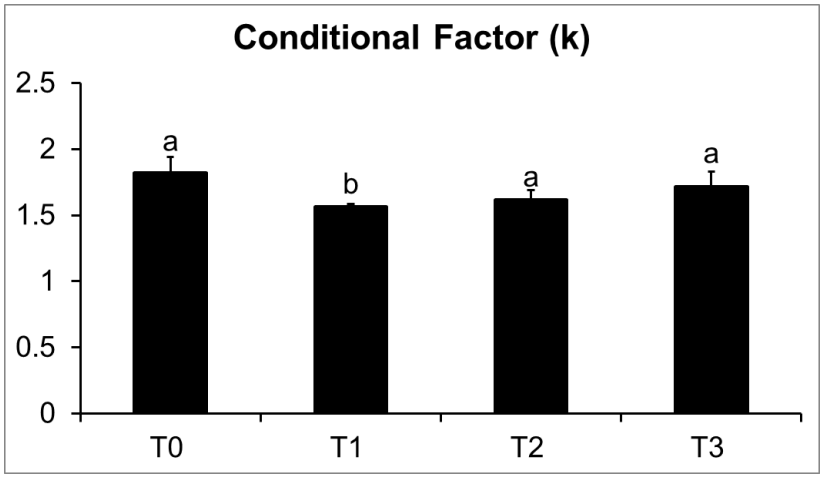


Figure 4. Fulton's condition factor (K) of tilapia at the end of the trial under each feed (mean ± SD). CCF = conventional commercial feed (T0), UUF = unfermented unconventional feed (T1), UFF = fermented unconventional feed (T2), and Hybrid = 50% CCF + 50% UFF (T3).

All growth metrics consistently followed the trend: T0 (commercial) > T3 (hybrid) >> T2 (fermented) ≥ T1 (unfermented). Statistical analysis confirmed significant treatment effects ($P<0.05$) for weight gain, SGR, and length gain.

Survival rates shown in Figure 5, differed significantly among treatments. The highest survival (100%) was achieved in both the fermented feed group (T2) and the hybrid feed group (T3). Fish fed the unfermented feed (T1) had slightly lower survival (93.3 ± 2.89%). Notably, the commercial feed group (T0) had the lowest survival at 76.67 ± 2.89%. Thus, feeds that produced the fastest growth (T0) yielded the lowest survival, whereas those with slower growth had near-perfect survival.

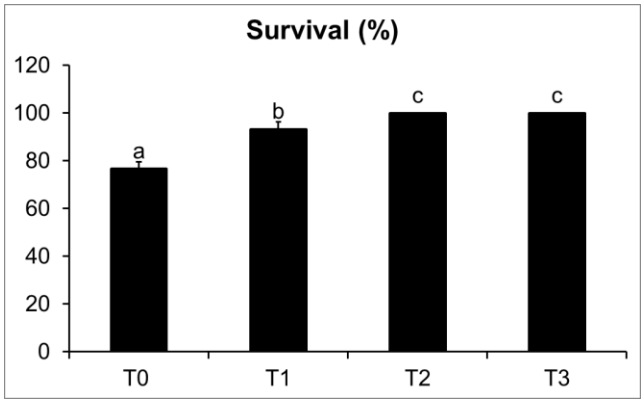


Figure 5. Survival rate (%) of tilapia over 58 days for each treatment (mean ± SD). CCF = conventional commercial feed (T0), UUF = unfermented unconventional feed (T1), UFF = fermented unconventional feed (T2), and Hybrid = 50% CCF + 50% UFF (T3).

Table 1. Proximate composition (% dry matter) of the treatment ingredients

Feed Ingredients	Moisture	Crude Protein	Crude Fat	Crude Fibre	Total Ash	NFE
UFWH	11.3	13.4	0.2	17.3	13.0	44.8
FWH	13.8	14.5	0.9	16.6	14.0	40.2

UFWL	13.8	14.4	3.7	13.4	14.6	40.1
FWL	14.7	15.9	4.4	12.3	15.2	37.5
UFEG	8.1	9.4	2.1	28.9	8.7	42.8
FEG	12.6	10.9	2.5	22.1	10.9	41.0

UFWH: Unfermented Water Hyacinth; FWH: Fermented Water Hyacinth; UFWL: Unfermented Water Lettuce; FWL: Fermented Water Lettuce; UFEG: Unfermented Elephant Grass; FEG: Fermented Elephant Grass

Table 2. Feed Formulation of the treatment feeds **(dry matter basis)**

Feed Ingredients	mg/g
Water Hyacinth (WH)	12
Water Lettuce (WL)	15
Elephant Grass (EG)	22
Blood Meal (BM)	36
Wheat Offal (WO)	8
Vitamin premix	1
Salt	0.5
Tallow	3.5
Lard	2
Total	100

Table 3. Proximate composition (% dry matter) of the treatment feeds**.**

Composition	**CCF (Control)**	**UUF (Unfermented Feed)**	**UFF (Fermented Feed)**
Moisture (residual)	13.93%	9.26%	8.32%
Crude Protein	34.16%	33.02%	37.97%
Crude Fat	3.11%	3.73%	6.43%
Crude Fibre	1.76%	9.79%	6.50%
Total Ash	9.55%	11.08%	9.39%
Nitrogen-Free Extract (NFE)	37.49%	33.12%	31.39%

Water Quality

Water quality remained acceptable immediately after water changes (D0) across all treatments (Table 4). However, by D1, the commercial feed (T0) consistently produced the poorest water conditions. Dissolved oxygen dropped sharply in T0, while tanks receiving unconventional feeds (T1–T3) maintained comparatively higher DO levels. Likewise, EC and TDS accumulated most rapidly in T0, indicating greater organic loading and waste buildup than in the alternative-feed treatments. pH remained near neutral across treatments, and ORP declined more strongly in T0, whereas T1–T3 retained higher ORP values. Overall, the unconventional feeds (especially T2 and T3) supported more stable water quality between renewal intervals, aligning with the higher survival rates observed in those treatments.

Table 4. Water quality parameters measured in each treatment, shown for immediately after water change (D0) and just before the next water change (D1). Values are mean ± SD (n = 3 per treatment)

Feed	pH (D0)	DO, mg/L (D0)	EC, µS/cm (D0)	TDS, ppm (D0)	ORP, mV (D0)	pH (D1)	DO, mg/L (D1)	EC, µS/cm (D1)	TDS, ppm (D1)	ORP, mV (D1)
T0	6.87 ± 0.03	7.47 ± 0.25	30.77 ± 6.27	16.00 ± 3.00	113.67 ± 1.15	7.77 ± 0.09	2.85 ± 0.21	94.33 ± 2.89	47.00 ± 1.73	37.33 ± 7.09
T1	6.93 ± 0.26	7.80 ± 0.10	26.00 ± 8.00	12.67 ± 4.04	112.00 ± 1.00	7.73 ± 0.03	3.90 ± 0.20	82.33 ± 6.03	42.33 ± 3.51	46.00 ± 0.58
T2	7.05 ± 0.05	7.53 ± 0.31	22.67 ± 5.51	11.00 ± 3.00	115.33 ± 3.06	7.75 ± 0.11	4.56 ± 0.21	77.00 ± 5.29	40.00 ± 2.65	47.12 ± 1.58
T3	6.91 ± 0.04	7.43 ± 0.24	26.23 ± 4.41	14.00 ± 2.00	114.67 ± 3.00	7.72 ± 0.08	4.64 ± 0.19	96.73 ± 0.18	47.00 ± 1.00	46.00 ± 0.02

Feed Cost Efficiency

The cost per kg of each feed differed dramatically (Table 5). The formulated unconventional feed (T1/T2) cost only about ₦120.8 kg^{-1} to produce. In contrast, the commercial feed (T0) cost approximately ₦1500 kg^{-1}. The 50:50 hybrid feed (T3) effectively halved the feed cost relative to using 100% commercial feed (since half of it was the ₦120 kg^{-1} feed and half the ₦1500 kg^{-1} feed). While we did not formally calculate an economic feed conversion ratio, the stark difference in ingredient cost suggests that the unconventional feeds would be far more economical, provided that acceptable fish growth and survival are achieved.

Table 5. Cost of ingredients and calculated cost per kg of formulated unconventional feed vs commercial feed.

Ingredient	Unit Cost (₦ kg^{-1})
Water Hyacinth (WH)	18.0
Water Lettuce (WL)	22.5
Elephant Grass (EG)	33.0
Blood Meal (BM)	36.0
Wheat Offal (bran)	2.24
Vitamin Premix	1.40
Salt	0.35
Tallow (beef fat)	4.90
Lard (pork fat)	2.40
Total (Formulated Feed)	**₦120.79** kg^{-1}
Commercial Feed	**₦1500** kg^{-1}

Alternative feed-efficiency and economic indices of Nile tilapia fed experimental diets

Estimated Feed Input

Estimated total feed offered per tank differed among dietary treatments over the 58-day trial (Table 6). Tanks receiving the commercial feed (CCF) had the highest cumulative feed input (185.6 g $tank^{-1}$), followed by the hybrid diet (149.4 g $tank^{-1}$). Lower total feed inputs were recorded for the unfermented (UUF) and fermented unconventional feed (UFF) treatments (133.4 g $tank^{-1}$ each), reflecting reduced

feed allocation and acceptance in these groups.

Table 6. Total feed offered per tank over 58 days

Diet	Total feed offered (g tank^{-1})
Control (T0)	185.6
UUF (T1)	133.4
UFF (T2)	133.4
Hybrid (T3)	149.4

Biomass Gain and Feed Utilization

Total biomass gain per tank varied among treatments. The highest biomass gain was observed in the commercial feed group (482.6 g tank^{-1}), followed by the hybrid diet (352.8 g tank^{-1}). Substantially lower biomass gains were recorded in the fermented (143.8 g tank^{-1}) and unfermented unconventional feed groups (114.6 g tank^{-1}). Biomass gain per feed offered (BGF) showed a similar trend (Table 7). The commercial feed recorded the highest BGF value (2.60), closely followed by the hybrid diet (2.36). In contrast, lower BGF values were observed for the fermented (1.08) and unfermented unconventional diets (0.86).

Table 7. Biomass gain per feed offered (BGF)

Diet	BGF
Control (T0)	2.60
UUF (T1)	0.86
UFF (T2)	1.08
Hybrid (T3)	2.36

Protein Utilization Efficiency

Protein efficiency ratio (PER) differed among dietary treatments (Table 8). The commercial feed group exhibited the highest PER (7.61), while the hybrid diet also showed a relatively high value (6.56). Lower PER values were recorded for the fermented (2.84) and unfermented unconventional feed treatments (2.61), indicating reduced efficiency of protein utilization in these diets.

Table 8. Protein efficiency ratio (PER) was calculated using total biomass gain and dietary crude protein content.

Diet	PER
Control (T0)	7.61
UUF (T1)	2.61
UFF (T2)	2.84
Hybrid (T3)	6.56

Economic Feed Efficiency

Feed cost conversion ratio (FCCR) varied substantially across treatments (Table 9). The lowest FCCR values were observed in the fermented (₦0.11 g^{-1} gain) and unfermented unconventional feed groups (₦0.14 g^{-1} gain), reflecting lower feed costs per unit biomass gain. The hybrid diet exhibited an intermediate FCCR value (₦0.34 g^{-1} gain), while the commercial feed

had the highest cost per unit gain (₦0.58 g^{-1} gain).

Table 9. Feed Cost Conversion Ratio (FCCR)

Diet	FCCR (₦/g gain)
Control (T0)	0.58
UUF (T1)	0.14
UFF (T2)	0.11
Hybrid (T3)	0.34

DISCUSSION

We examined the use of locally available, unconventional ingredients, fermented plants and animal by-products as a cost-effective alternative to commercial tilapia feed. The goal was to assess whether such feed could support fish growth while improving survival, water quality, and affordability in low-input systems. The results showed a clear trade-off between maximizing tilapia growth and minimizing feed cost and environmental impact. Fish fed the unconventional, plant-based feed grew considerably slower than those on commercial feed, but they had markedly higher survival rates and maintained better water quality. The experimental low-cost feeds were formulated from locally available plants (water hyacinth, water lettuce, and Napier grass), combined with animal by-products (blood meal and rendered fat), with fermentation used to enhance their nutritive value. The results indicate that while such feed can support tilapia production at a fraction of the cost of commercial feed, they require compromises in growth performance.

Growth Performance and Nutritional Factors

Fermentation of the plant ingredients substantially altered their composition, increasing crude protein and reducing crude fiber content which is expected to improve digestibility in plant-based feeds (Sun *et al*., 2023; Lian *et al*., 2024; Siddik *et al*., 2024). In this study, however, the fermented feed provided only a modest improvement in fish growth compared to those fed unfermented feed. Fish fed both unconventional feed (fermented and unfermented) achieved only a fraction of the weight gain observed in the commercial-feed group. This suggests that factors beyond crude nutrient content limited growth, with feed intake and palatability being primary issues. We observed a considerable amount of uneaten feed in the tanks receiving the unconventional feeds, indicating that the fish did not consume enough for optimal growth. The high inclusion of blood meal (~36% of total protein) and fibrous plant matter likely reduced the feed's palatability. Kirimi *et al*. (2016) and Macusi *et al*. (2023) similarly observed that excessive blood meal can lower feed intake in Nile tilapia due to its poor palatability (Kirimi *et al*., 2016; Macusi *et al*., 2023). Additionally, while blood meal is rich in protein (especially lysine), it is deficient in certain essential amino acids (e.g., isoleucine and threonine). The absence of any fishmeal or soybean meal in these formulations meant that some critical amino acids and natural feed attractants were lacking, which further contributed to poor growth despite adequate crude protein levels (Emshaw *et al*., 2023; Macusi *et al*., 2023; Zhang *et al*., 2023). Previous studies

suggest that even fermented aquatic plants can be included up to around 20–30% of a tilapia diet without compromising growth, but beyond this threshold, performance declines markedly (El-Sayed, 2003; Wokeh *et al.,* 2025). In our study, the inclusion level likely exceeded the fish's tolerance, resulting in suboptimal nutrient uptake and utilization. Nonetheless, all fish fed the unconventional feed remained in generally good health throughout the trial. No deformities or deficiency symptoms were observed, and the final Fulton's condition factors (K) of these fish were within a normal healthy range (~1.6–1.7). This indicates that the experimental feeds, despite their shortcomings in promoting rapid growth, met the basic nutritional requirements for maintenance and kept the fish in acceptable physiological condition.

Feed utilization efficiency and economic implications

Although conventional feed conversion ratio (FCR) could not be calculated due to group feeding, alternative efficiency indices provided valuable insights into dietary performance. Biomass gain per feed offered (BGF) followed a pattern consistent with observed growth responses, with the commercial feed exhibiting the highest efficiency, closely followed by the hybrid diet. This indicates that partial replacement of commercial feed with fermented unconventional ingredients preserved much of the feed-use efficiency while substantially reducing feed input and cost. Protein efficiency ratio (PER) values further highlighted differences in nutrient utilization among diets. The lower PER observed in the unfermented and fermented unconventional feeds suggests reduced efficiency of protein utilization, likely due to a combination of high fiber content, residual anti-nutritional factors, and suboptimal amino acid balance resulting from the absence of fishmeal and soybean meal. Fermentation improved PER modestly relative to the unfermented diet, supporting the role of bioprocessing in enhancing nutrient availability. From an economic perspective, feed cost conversion ratio (FCCR) favoured the unconventional diets, particularly the fermented feed, which exhibited the lowest cost per unit biomass gain. The hybrid diet demonstrated an intermediate FCCR, reflecting a favorable balance between growth performance and cost efficiency. This trade-off underscores the practical relevance of hybrid feeding strategies for resource-limited aquaculture systems, where minimizing feed costs may be prioritized over maximizing growth rate. Overall, the combined efficiency and economic indices demonstrate that while full replacement of commercial feed with unconventional ingredients compromises growth and nutrient utilization, partial replacement can achieve acceptable efficiency at substantially reduced cost. These findings align with the study's objective of evaluating low-competition, sustainable feed resources for tilapia culture.

Survival and Water Quality

A striking outcome was the significantly higher survival of fish fed the unconventional feeds, especially in the fermented-only (T2) and hybrid (T3) groups, which achieved 100% survival, compared to about 77% survival in the commercial feed group (T0). This discrepancy is closely linked to differences in water quality among the treatments. Fish fed the commercial diet consumed more and consequently produced more waste (uneaten feed and excreta), leading to faster accumulation of organic matter and ammonia in the water. As a result, water quality in the T0 tanks deteriorated more rapidly between water changes. By the end of each 3-day water exchange cycle, dissolved oxygen levels in the commercial-feed tanks had dropped to around 2.8 mg/L, a level that can severely stress or even kill Nile tilapia (Torres-Beristain *et al*., 2006)

while metabolic wastes built up. In contrast, the tanks receiving the maintained good water quality conditions throughout the culture period. These observations align with the findings of El-Sayed (2003), who reported that including water hyacinth meal up to 20% did not significantly harm water quality in tilapia culture (El-Sayed, 2003). The better water quality in the unconventional-feed treatments likely reduced physiological stress on the fish, thereby improving their survival. Another potential benefit of the fermented feed was the introduction of beneficial microbes and metabolites that promote fish health (Neves *et al*., 2024; Siddik *et al*., 2024). Although we did not directly measure microbiological or immunological parameters, the absence of any disease signs and the excellent survival in the fermented and hybrid diet groups suggest a positive influence of these fermented ingredients on fish resilience. Overall, the unconventional feed treatments created a more "low-impact" rearing environment: the fish ate less and grew slower, but water quality was more stable and survival rates were higher. This trade-off might be advantageous in low-input or static water aquaculture systems where high water quality is difficult to maintain and losses from poor water conditions can be catastrophic.

Economic and Environmental Implications

The primary advantage of the unconventional diets is their drastically lower cost. We estimated the formulated plant-based feed to cost roughly ₦120 per kg, compared to about ₦1500 per kg for the commercial tilapia feed. This is over a 90% reduction in feed cost. Given that feed often accounts for 50–70% of the operating expenses in tilapia farming (FAO, 2020), replacing commercial feed with locally sourced alternatives could greatly improve the profitability and feasibility of small-scale aquaculture. For resource-limited or subsistence farmers, the ability to use a homemade feed made from inexpensive, readily available materials can make fish farming much more accessible and financially sustainable.

In addition to cost savings, there are significant environmental benefits to using these unconventional feed ingredients. Harvesting invasive aquatic plants for feed helps control their spread in natural water bodies, turning an ecological nuisance into a valuable resource. Likewise, recycling slaughterhouse by-products like blood meal and rendered fat into fish feed prevents those waste materials from polluting the environment, while also reducing the demand for conventional feed ingredients. This approach aligns with the circular economy principle of resource valorization (Naylor *et al*., 2021). Although blood meal has been successfully used as a partial or complete fishmeal substitute in tilapia diets, inclusion levels above those typically recommended for optimal growth can reduce palatability and limit amino acid balance. The high inclusion level used in this study therefore represents a deliberate cost-driven formulation extreme, highlighting both the economic potential and nutritional constraints of relying heavily on animal by-products

Hybrid Feeding Strategy

The 50:50 hybrid diet (half commercial feed and half fermented feed) emerged as a promising compromise. Growth performance in the hybrid group was intermediate – considerably better than the all-plant diets, though still below the all-commercial feed – but this was achieved at roughly half the feed cost of the commercial diet. In practical terms, the hybrid-fed fish reached about 70–75% of the weight gain of the control fish, a substantial improvement over the purely unconventional diets, and did so with a dramatic reduction in feed expense. This outcome underscores the potential of partial

feed replacement: by blending a portion of high-quality commercial feed with a portion of cheap, locally sourced feed, farmers can strike a balance between performance and cost. Similar successes with partial replacement have been noted in other studies; for instance, Raswin *et al*. (2024) reported that substituting about 30–50% of commercial feed with alternative ingredients sustained tilapia growth while cutting feed costs by up to ~40%. In our study, the inclusion of some commercial feed likely enhanced the overall palatability and nutritional balance of the diet (providing missing amino acids, lipids, and attractants), thereby encouraging feed intake and supporting much better growth than the 100% unconventional feed.

CONCLUSION

This study illustrates that locally available, fermented plant materials combined with animal by-products can be used to formulate a viable tilapia feed that dramatically lowers cost and environmental impact. The fermented plant-based diets supported acceptable tilapia survival and health, and they maintained good water quality, albeit at the cost of slower growth compared to commercial feed. For small-scale and sustainable aquaculture, this trade-off can be acceptable – especially when using a hybrid feeding approach that mixes commercial and alternative feeds. A 50:50 blend, in particular, achieved moderate growth (approximately three-quarters of the commercial feed group's weight gain) with 100% survival, while reducing feed costs by about half. With further refinement to improve nutritional quality and palatability (through enhanced fermentation techniques and nutrient supplementation), these unconventional feeds could help make aquaculture more affordable and eco-friendly. In effect, this approach turns problematic plants and waste products into productive resources for fish farming, allowing farmers to reduce expenses and environmental impacts while still maintaining viable production.

Conflict of Interest

The author(s) declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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Author Contribution Statement

EUK: Conceptualization, Methodology, Experimental Design, Experimental Trials, Data Collection, Statistical Analysis, Writing Original Draft, Review and Editing, Project Administration. EA, CPN, IOP, and ABO: Experimental Setup, Experimental Trials, Data Collection. All authors reviewed and approved the final version of the manuscript prior to submission

REFERENCES

AOAC. (2019). *Official methods of analysis of AOAC International* (21st

ed.). Association of Official Analytical Chemists.

Bake, G. G., Adebayo, I. A., and Akinyemi, A. A. (2015). Effects of fermented legume seed meal on growth and feed utilization in catfish (*Clarias gariepinus*). *Indian Journal of Animal Research, 49*(6), 783–789.

Bureau, D. P., and Meeker, D. L. (2010). Terrestrial animal fats. *Fish oil replacement and alternative lipid sources in aquaculture feeds. CRC Press, Boca Raton, FL*, 245-266.

El-Sayed, A. F. M. (2003). *Effects of fermentation methods on the nutritive value of water hyacinth for Nile tilapia (Oreochromis niloticus (L.)) fingerlings.* Aquaculture, 218(1-4), 471–478.

Emshaw, Y., Getahun, A., and Geremew, A. (2023). *Effect of different levels of fermented water hyacinth leaf meal on feed utilization and performance of juvenile Nile tilapia*. Online Journal of Animal and Feed Research, 13(1), 55-62.

FAO. 2020. *The State of World Fisheries and Aquaculture 2020*. *Sustainability in action*. Rome. https://doi.org/10.4060/ca9229en

Gao, F., Liu, M., Tang, J., Wang, A., Tian, H., Wen, C., ... and Zhang, D. (2021). Partial replacement of dietary fish oil by beef tallow does not impair antioxidant capacity and innate immunity of red swamp crayfish, Procambarus clarkii. *Aquaculture Research*, *52*(7), 3310-3321.

Kirimi, J. G., Musalia, L. M., Magana, A., and Munguti, J. M. (2016). *Performance of Nile Tilapia (Oreochromis niloticus) Fed Diets Containing Blood Meal as a Replacement of Fish Meal. Journal of Agricultural Science, 8*(8), 79–89.

Kokou, F., and Fountoulaki, E. (2018). Aquaculture waste production associated with antinutrient presence in common fish feed plant ingredients. *Aquaculture*, *495*, 295-310.

Kuangkam, P., Whangchai, N., Pimpimol, T., Senphan, T., Puntharod, R., and Sompong, U. (2024). Enhancing enzyme digestibility of red tilapia (Oreochromis niloticus and O. mossambicus) and improving water quality in fish farming using Napier grass silage. *Agriculture and Natural Resources*, *58*(1), 89-100.

Kumar, G., Sharma, J., Goswami, R. K., Shrivastav, A. K., Tocher, D. R., Kumar, N., and Chakrabarti, R. (2022). Freshwater Macrophytes: a potential source of minerals and fatty acids for fish, poultry, and livestock. *Frontiers in nutrition*, *9*, 869425.

Lian, X., Shi, M., Liang, Y., Lin, Q., and Zhang, L. (2024). The effects of unconventional feed fermentation on intestinal oxidative stress in animals. *Antioxidants*, *13*(3), 305. doi: 10.3390/antiox13030305.

Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., ... and Troell, M. (2021). A 20-year retrospective review of global aquaculture. *Nature, 591*(7851), 551–563.

Neves, N. O. D. S., De Dea Lindner, J., Stockhausen, L., Delziovo, F. R., Bender, M., Serzedello, L., ... and Perez Fabregat, T. E. H. (2024). Fermentation of plant-based feeds with Lactobacillus acidophilus improves the survival and Intestinal

health of juvenile Nile tilapia (Oreochromis niloticus) reared in a Biofloc System. *Animals*, *14*(2), 332.

Nisha, S. N., and Geetha, B. (2017). Effect of partial replacement of fishmeal with aquatic weed Pistia stratiotes meal on growth, biochemical composition, haematological parameters and digestive enzymes in Indian major carp Labeo rohita (Hamilton, 1822). *International Journal of Fisheries and Aquatic Studies*, *5*(2), 527-532.

Macusi, E. D., Subprasom, S., and Tacon, A. G. J. (2023). Protein fishmeal replacement in aquaculture: A review of alternative protein sources, amino acid adequacy, and palatability in fish diets. *Sustainability*, *15*(16), 12500.

Pandey, A. (2020). Water hyacinth as potential feed and compost in aquaculture: A review. *Journal of Entomology and Zoology Studies*, *8*(5), 1434-1437.

Raswin, K., Prakash, J., and Kumar, A. (2024). Growth performance and economic analysis of tilapia fed diets containing fermented water hyacinth meal. *Indian Journal of Animal Research*, *58*(4), 653–660.

Saha, S., and Ray, A. K. (2011). Evaluation of nutritive value of water hyacinth (Eichhornia crassipes) leaf meal in compound diets for rohu, Labeo rohita (Hamilton, 1822) fingerlings after fermentation with two bacterial strains isolated from fish gut. *Turkish Journal of Fisheries and Aquatic Sciences*, *11*(2).

Siddik, M. A., Julien, B. B., Islam, S. M., and Francis, D. S. (2024). Fermentation in aquafeed processing: Achieving sustainability in feeds for global aquaculture production. *Reviews in Aquaculture*, *16*(3), 1244-1265.

Sun, H., Kang, X., Tan, H., Cai, H., and Chen, D. (2023). Progress in Fermented Unconventional Feed Application in Monogastric Animal Production in China. *Fermentation*, *9*(11), 947.

Torres-Beristain, B., Verdegem, M., Kerepeczki, E., and Verreth, J. (2006). Decomposition of high protein aquaculture feed under variable oxic conditions. *Water research*, *40*(7), 1341-1350.

Tran, N., Shikuku, K. M., Rossignoli, C. M., Barman, B. K., Cheong, K. C., Ali, M. S., and Benzie, J. A. (2021). Growth, yield and profitability of genetically improved farmed tilapia (GIFT) and non-GIFT strains in Bangladesh. *Aquaculture*, *536*, 736486.

Trushenski, J. T. and Lochmann, R. T. (2009). Potential, Implications and Solutions Regarding the Use of Rendered Animal Fats in Aquafeeds. *American Journal of Animal and Veterinary Sciences*, *4*(4), 108-128.

Wokeh, O. K., Komi, G. W., and Hart, A. I. (2025). Effects of Water Lettuce *Pistia stratiotes* substitution on growth and health of Nile tilapia (*Oreochromis niloticus*). *Asian Journal of Fisheries and Aquatic Research*, *27*(9), 40-49.

WorldFish. (2021). The GIFT that keeps giving. In: WorldFish. Penang, Malaysia. Cited8 September 2021. www.worldfishcenter.org/pages/gift